

CHARACTERIZATION OF LOADING EFFECTS IN PRECISION 1 Ω RESISTORS

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Abstract

Precision standard resistors manufactured within the last two decades using improved construction techniques and materials, such as the resistance alloy Evanohm[‡], have been shown to have excellent environmental characteristics. Power dissipation (or loading) effects in several types of resistors have been examined including specifically those made of Manganin[‡] and Evanohm, and with the resistor element both sealed within a double wall container, or unsealed. Our recent tests on these resistors demonstrate that conditions of power dissipation within the resistors and the duty cycle of the power applied to the resistor have significant effect on the uncertainty of the measurement.

Introduction

The National Institute of Standards and Technology (NIST) incorporates a bank of five Manganin alloy, Thomas-type 1 Ω resistors as primary working standards for comparisons using a precision potentiometer DC current comparator (DCC). This bank was the national standard for the unit of resistance in the United States prior to the acceptance of the quantum Hall resistance (QHR) as the international representation of the ohm in 1990. They remain a stable reference whose average drift and environmental characteristics are well documented. Complete characterization for the effects of temperature, pressure, humidity, and applied current allows National Measurement Institutes (NMIs) to compare these types of resistors with low uncertainty in key comparisons [1,2].

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[‡] Certain commercial equipment, instruments, or materials are identified in this paper to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

At NIST most primary working standards are compared against the QHR standard approximately twice a year in order to maintain and predict the value. This process was the focus of a comparison of QHR measurement systems between NIST and the Bureau International des Poids et Mesures (BIPM) in the year 1999 [3]. This showed agreement in scaling to within a relative uncertainty of 31 parts in 10^{10} at the 1 Ω level. More recently, a comparison between NIST and the BIPM was carried out in May 2007 using three 1 Ω traveling standards from the BIPM [4]. These resistors were designed and manufactured at the Australian National Measurement Laboratory (NML, now part of the National Measurement Institute Australia NMIA). The result of this intercomparison was a difference between the two NMIs of -0.014×10^{-6} with an expanded uncertainty ($k = 2$) of 0.042×10^{-6} .

NIST uses three similar 1 Ω resistors of the NML type as our transfer standards for the scaling comparison at the 1 Ω level. The NIST scaling procedure begins with a bank of five precision 100 Ω resistors that are compared against the QHR using a cryogenic current comparator (CCC) system designed and constructed at NIST. The 1 Ω transfer resistors are then measured against these 100 Ω resistors through a second CCC system. Finally, the three 1 Ω transfer resistors are returned to the DCC system and measured against our primary working standards. Any difference between the resistance value for these resistors as determined by the DCC system and the QHR-CCC system results in an adjustment to the group mean of the five working 1 Ω standards. Typically the difference between these values is on the order of a few parts per billion.

Power Loading Effects

It has been shown that the temperature coefficient of an Evanohm coil varies along the length of the winding [5], and if a temperature gradient is produced by loading, this can produce changes in the measured value of the resistance. The mechanisms for the change in resistance under load may also include second order thermoelectric effects resulting from the product of thermal gradients and the measurement current (Thomson effect).

In the DCC system the current is applied continuously and its polarity is switched within milliseconds, which results in essentially 100% duty cycle. The current in the CCC systems is ramped from one direction to the other over a period of several seconds. Measuring the resistors in the CCC system also removes any effect of power loading of the standards, as the 100 Ω resistors operate at very lower power levels in the CCC system. Experiments that are sensitive to relative power loading effects were conducted by comparing the results of these two systems.

Several other comparisons have been used to identify the source of loading effects that have been observed. Modifications were made to a second, nearly identical precision 1 Ω DCC measurement system to allow the current to bypass up to three test resistors until a predetermined time. This allows those resistors to be measured from an initial condition of zero current, as in the CCC and many commercial instruments. Additional tests placed the resistors within a separate oil bath with a high flow rate in the circulating oil, which should reduce any thermal gradients along the resistor elements.

A series of experimental procedures were performed on a number of Thomas-type and NML resistors. Initially measurements were made with the second DCC system at 100 mA (10 mW) at 100% duty cycle to establish a base line of resistor values. These measurements were repeated periodically to determine if there had been any shifts in the resistance values. Then measurements were made at 100 mA with the power off in the test resistors except when each unit was to be measured. This DCC system was then reconfigured to operate at 50 mA (2.5mW), and the measurements were repeated. Measurements were also made using the CCC systems at both 100 mA and 50 mA.

So far, four Manganin and eight Evanohm resistors have been measured in these experiments. It should be noted that resistors of the Thomas-type (Manganin) typically have a temperature coefficient of resistance (TCR) of approximately 2.4 ($\mu\Omega/\Omega$)/ $^{\circ}\text{C}$ and those of Evanohm have TCRs of approximately -0.23 ($\mu\Omega/\Omega$)/ $^{\circ}\text{C}$ [6]. Measurable shifts have been detected in the value of all but one of the test resistors when cycling the current at 100 mA. The relative changes in value for many of these different test conditions were approximately 1×10^{-8} to 3×10^{-8} . Furthermore, the direction of the shift was not consistent among the Evanohm test resistors; some

decreased in value whereas others increased in value. When using 50 mA most variations between full duty cycle and power cycling were less than 1×10^{-8} . The results using the CCC system were consistent with those obtained using the DCC system.

Conclusions and Acknowledgements

At 10 mW power load, precision 1 Ω resistors exhibit a measurable systematic uncertainty that depends on how power is applied to the resistor. This systematic uncertainty is reduced by measuring the resistors at a lower current level of 50 mA, however the Type A standard uncertainty in our DCC system increases from 0.003 $\mu\Omega/\Omega$ to 0.005 $\mu\Omega/\Omega$ at this current. Detailed observations and an analysis of loading effects will be presented at the conference. We would like to acknowledge the invaluable assistance of Brian Pritchard of the National Measurement Institute, Australia, in the form of many discussions of power loading effects and the loan of several NML resistors used in these tests.

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